Investment conditions for a timely energy transition: An analysis through an agent-based, SFC input-output model

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Abstract

Our model aims to provide relevant contributions to the literature through innovations in modelling methodology and by addressing research questions related to the energy transition.

As for the modelling methodology, we build what is probably the first macroeconomic model that fully integrates the methodology underlying the Leontief input-output quantity model with heterodox dynamic macro-modelling. In addition to a household, a bank, a government, and a central bank, our framework features six highly interdependent industrial sectors, producing five types of goods: minerals, fossil fuels, manufacturing goods, miscellaneous goods/services, and electricity through either renewables or fossil fuels. Each industry needs intermediate inputs and investment goods from all the others in order to produce. We improve upon the Leontief model by (i) introducing production constraints that can arise from limits in the availability of capital or intermediate inputs; and (ii) by allowing for perfect substitutability between green and brown electricity (with grid priority for the first), thereby departing from the assumption of perfect complementarity between intermediate inputs.

As for the energy transition, our policy experiments yield interesting insights. Firstly, a low-carbon scenario—characterized by a high share of green electricity, resulting from a green subsidy policy—features a lower GDP growth rate than a high-carbon scenario—defined by a low share of green electricity. The reason is that the low-carbon scenario features an economy that requires less intermediate inputs (fossil fuels are substituted with sun and wind), thus less production and less investments, and therefore a lower GDP growth than a high-carbon scenario. Secondly, the energy transition entails a structural change in the industrial pattern of the economy: apart from the obvious rise of the green electricity sector and decline of the brown electricity sector, the transition brings along a growing minerals industry, and declining fossil fuels, manufacturing, and miscellaneous industries.

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1 Introduction

The urgency of tackling climate change requires, first and foremost, a rapid worldwide shift from electricity generation and transport systems based on fossil-fuels to energy systems based on renewable resources. Conventional thermoelectric power plants typically use fossil fuels (such as coal, gas, and oil) as intermediate inputs in the production of electricity; conventional vehicles require fossil fuels to function. In both cases, the combustion process releases greenhouse gases (GHGs) in the atmosphere, thereby heavily contributing to climate change. Power generation based on renewables, instead, uses—as intermediate inputs—free resources such as sun and wind, which are available at no cost and do not generate GHGs when converted into electricity. Electric vehicles require electricity to charge their batteries, and that electricity can be produced through green power generation systems.

However, while having the upside of putting an end to the direct use of fossil fuels and to the resulting GHGs emissions, the downside of green technologies is that building solar photovoltaic (PV) plants, wind farms and electric vehicles (EVs) generally requires much more minerals than their fossil fuel-based counterparts. This has been recently emphasized in a report by the International Energy Agency (IEA, 2021b). A typical electric car requires six times the mineral inputs of a conventional car, and an onshore wind plant requires nine times more mineral resources than a gas-fired power plant (for the same level of power capacity), as shown in figure 1. The types of mineral resources used vary by technology. Lithium, nickel, cobalt, manganese and graphite are crucial to battery performance, longevity and energy density. Rare earth elements are essential for permanent magnets that are vital for wind turbines and EV motors. Electricity networks need a huge amount of copper and aluminium, with copper being a cornerstone for all electricity-related technologies.

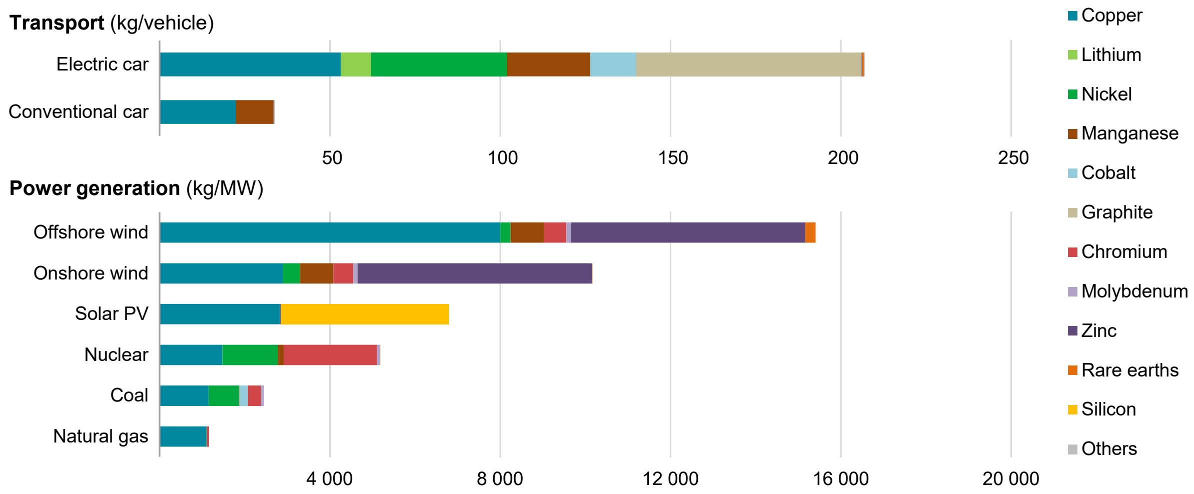
As warned by the IEA, today's mineral supply and investment plans fall short of what is needed to transform the energy sector, raising the risk of delayed or more expensive energy transitions. For instance, looking ahead in a scenario consistent with climate goals, by 2030 expected supply from existing mines and projects under construction is estimated to meet only 50% of projected lithium and cobalt demand and 80% of copper requirements. In addition, the IEA stresses, there are several vulnerabilities that may increase the possibility of market tightness and greater price volatility:

- Long project development lead times: It has taken on average over 16 years to move mining projects from discovery to first production. These long lead times raise concerns about the ability of suppliers to meet a rapidly growing demand.

- Declining resource quality: In recent years, ore quality has continued to fall across a range of commodities. For instance, the average copper ore grade in Chile dropped by 30% over the last 15 years. Extracting metal content from lower-grade ores demands more energy, leading to higher production costs, greenhouse gas emissions and waste volumes.

- Mining assets are exposed to growing climate risks. Given their high water requirements, copper and lithium are particularly vulnerable to water stress: over 50% of today's lithium and copper production is located in areas with high water stress levels. Several major producing countries and regions such as Australia, China, and Africa are subject to extreme heat or flooding, which pose greater challenges in ensuring reliable and sustainable supplies.

Figure 1: Minerals used in selected energy technologies



Source: IEA (2021b, pg. 6), The Role of Critical Minerals in Clean Energy Transitions. All rights reserved.

Raw materials are a significant element in the cost structure of many technologies required in energy transitions, implying that increasing prices of minerals may negatively affect the profitability of investments in green energy technologies. In its 2021 report on renewables (IEA, 2021a), the IEA has estimated that the overall investment cost of utility-scale solar PV and onshore wind plants could increase by around 25% due to the commodity price surge, based on a comparison of average commodity prices between 2019 and 2021.

To cope with the challenges mentioned above, the IEA suggests the following strategies: (i) policy makers should provide clear and strong signals about energy transitions: if companies do not have confidence in countries' energy and climate policies, they are likely to make investment decisions based on much more conservative expectations; (ii) reducing material intensity and encouraging material substitution via technology innovation; (iii) improving recycling practices; and (iv) tackling emissions associated with mining and processing of minerals.

To summarize, transitioning to an economy based on renewable energy systems will result in a structural change within the industrial pattern of the economy itself[1]. Shutting down fossil fuel-based power plants and banishing conventional cars will lead to a severe contraction of the fossil fuels sector, thereby negatively affecting also its suppliers (Cahen-Fourot et al., 2021). Electricity generation through renewables doesn't require any commodified energetic inputs, as sun and wind are freely available. Therefore, fossil fuels producers won't be replaced by any (bizarre) sun and wind producers. However, as detailed above, green technologies for electricity production and transport require much

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[1] Cahen-Fourot et al. (2020) demonstrate the structural and crucial importance of raw materials—including both fossil fuels and minerals—in providing the necessary inputs to modern European economies, contributing to the economic system with a far more essential role than what the GDP share of extractive sectors would suggest. They conclude that the shift to renewables will affect not only the raw materials sector itself, but downstream sectors as well that currently depend on nonrenewable resources.

more mineral inputs than their fossil fuel-based counterparts. Therefore, it is likely that the relative weight of the mining and processing of minerals sectors will grow, compared to other industrial sectors. However, the supply of minerals in the medium and long term may fall short of demand, potentially hampering the energy transition itself.

Given the considerations made above, we believe that it is necessary to address the following research questions:

(i) What are the implications of the energy transition on the industrial structure of the economy and on macroeconomic dynamics (e.g. unemployment, investment, etc.)?

(ii) Under which conditions of relative investment and operating costs a timely energy transition could be achieved? In other words, from the perspective of private investors, what are the main drivers of the relative attractiveness of investments in green versus brown energy technologies?

(iii) What are the effects of policies such as government subsidies to private investments in green electricity technologies?

(iv) What are the environmental costs of the energy transition?

To address such issues, it is useful to rely on a macroeconomic model with the following features:

(i) An industrial structure comprising several industries, modeled as an input-output network. This allows to capture the network effects of a sharp decline in the use of fossil fuels for electricity generation and transport and of a strong increase in green energy technologies.

(ii) Dynamic: the economy needs to evolve over time.

(iii) Calibrated on real data.

Traditional input-output models are static: given an exogenous change in final demand for each sectoral product (or service), assuming fixed prices, such models compute the resulting change in total production of each industrial sector (Miller and Blair, 2009, Ch. 2). The change in total production is typically much larger than the change in final demand, because each industrial sector needs intermediate inputs from other sectors in order to produce its final product. Therefore, each industry has to produce more than its final demand, as it has to supply intermediate inputs to the other industries. In addition, input-output models assume perfect complementarity between intermediate inputs: for each industry, the quantity of each intermediate input needed to produce one unit of the industry's output is assumed to be fixed; substitution between intermediate inputs is impossible.

We propose a macroeconomic model combining the input-output methodology with the Stock-Flow Consistent (SFC) approach to macro-modeling (Godley and Lavoie, 2007; Nikiforos and Zezza, 2017), with most behavioral equations rooted in the Post-Keynesian (Lavoie, 2022) and evolutionary stream of literature, thereby obtaining a model featuring non-linear, out-of-equilibrium dynamics[2]. We provide a relevant contribution to the

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[2] The combination of input-output analysis with SFC modelling was identified by Hardt and O'Neill (2017) as a promising avenue for developing macroeconomic models investigating environmental-economic issues.

literature not only by addressing the research questions mentioned above, but also by improving the modeling methodology. Firstly, to the best of our knowledge, our model seems to be the first one that integrates the methodology underlying the Leontief input-output quantity model (Miller and Blair, 2009, Ch. 2) with heterodox dynamic macroeconomic modelling. Secondly, we improve upon the Leontief input-output quantity model in two ways:

(i) we introduce production constraints that can arise from limits in the availability of capital or intermediate inputs.

(ii) we depart from the assumption of perfect complementarity between intermediate inputs by allowing for perfect substitutability between green and brown electricity (with grid priority for the first).

We rely on the world-level Exiobase 3 input-output dataset[3] for 2011 to calibrate our model's industrial technical coefficients, the households' desired consumption proportions of different goods and services, and the proportions of goods comprising the generic capital good.

The model presented in this work focuses on the transition from electricity generation based on fossil-fuels to electricity generation based on renewables. We leave aside the related issue of shifting transport systems from fossil-fuels to electricity, which may be added in a follow-up paper.

The rest of the paper is structured as follows. Section 2 discusses relevant literature. In Section 3, we present our model. Simulation results are examined in Section 4.

2 Related Literature

In this section, we will discuss the literature of heterodox dynamic macroeconomic models that are relevant to either of our model's two contributions, namely:

(i) the research question confronting the crucial role played by minerals in the energy transition—or, more generally, the relevance of material inputs to econonomic systems;

(ii) the methodology of combining input-output analysis with dynamic macroeconomic modelling.

We will present the contributions on the two issues separately and according to the above order. While we do not aim to provide an exhaustive list, we will discuss the contributions that—to the best of our knowledge—are more relevant for our own.

A few contributions within the ecological macroeconomics literature have introduced a role for material inputs in their models. Among the others, Dafermos et al. (2017) and Deleidi et al. (2019) develop SFC models where physical stocks and flows of matter and energy are explicitly formalised, taking into account the the First and the Second Law of Thermodynamics. Both models account for the fact that supply constraints might arise due to the exhaustion of natural resources. While Dafermos et al. (2017) show that green

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[3] The Exiobase 3 database can be accessed at the following link: https://doi.org/10.5281/zenodo.5589597

finance policies have favourable effects on environmental variables, Deleidi et al. (2019) demonstrate that the government can be successful in supporting innovation and growth while slowing down matter and energy reserves' depletion rates. However, both models lack a multisectoral input-output representation of the industrial system: there is just one type of firm that produces a homogeneous good; matter and energy are inputs that come from outside the economy, being directly extracted (and recycled, in the case of matter) by the firm itself.

There are some works that have attempted to embed the input-output methodology in a dynamic framework. It turns out that our model seems to be among the first ones that fully integrate the methodology underlying the Leontief input-output quantity model (Miller and Blair, 2009, Ch. 2) with heterodox dynamic macroeconomic modelling.

Berg et al. (2015) develop a SFC input-output model with two industrial sectors—an energy sector and a generic goods sector—to offer interesting macroeconomic and environmental insights related to energy price shocks, heat emissions, and the role of interest rates. The model is relatively simple and assumes capital away. It works smoothly, since no constraints are present: the two industries face no limits in production—as intermediate inputs and labor are disposable in unlimited amounts—and bank credit (necessary to finance inventories) is infinitely available. In addition, the model does not rely on the Leontief quantity model to compute each industry's total production as a result of (expected) final demand. Rather, each industry produces a total amount equal to a targeted change in inventories plus expected gross sales—which depend on past gross sales[4].

Jackson and Jackson (2021) build a SFC input-output model to investigate the economic and financial implications of an energy technology transition involving a reduction in energy return on investment (EROI). An important takeaway from this work is that reductions in EROI are likely to negatively impact the economy. The input-output industrial structure of the model comprises an energy sector, a capital goods sector, and a "other goods" (non-energy, non-capital) sector. Our understanding is that the Leontief input-output computation is only used to measure the EROI, by calculating the total (direct plus indirect) energy production that is required to produce a single unit of energy. However, it is not used to compute each sector's total (desired or actual) production as a result of expected final demand.

Poledna et al. (2020) develop a large-scale Agent-Based model that can compete with and in the long run significantly outperform benchmark VAR and DSGE models in out-of-sample forecasting of macro variables. Parameters are set for the Austrian economy, using a scale of 1:1 between model and data, so that each agent in the model represents a natural or legal person in reality. The industrial structure of the model comprises 64 industry sectors according to national accounting conventions (NACE/CPA classification by the European System of Accounts). Each of these industrial sectors comprises heterogeneous agents (firms). However, all firms belonging to the same sector share the same technical coefficients, which are calculated directly from input-output tables. The model does not rely on the Leontief quantity model to compute each firm's total (desired or actual) production as a result of expected final demand. Instead, each firm sets its desired production level equal to expected sales to final and intermediate demand, and these expected sales are equal to previous period sales multiplied by the expected real economic growth. Actual production may be less or equal to desired production depending on the

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[4] Gross sales include sales to households, sales to the government, and sales to the other industry that buys the product for intermediate input use.

availability of labor, capital, and intermediate inputs accumulated during the previous period. All these production factors are not substitutable between each other (Leontief production function).

Reissl et al. (2022b) build a novel interregional computational input–output model (IRIO-LockI) to assess the short-term economic impact of Covid-19 lockdowns in Italy. Such model is able to closely reproduce the observed economic dynamics during spring 2020. It features 32 sectors for each Italian region—with constant technical coefficients derived from input-output tables—and allows for a sequential adjustment process in response to shocks to productive capacity (supply shocks) and/or to final demand (demand shocks). The original version of IRIO-LockI focuses mainly on supply-side impacts of lockdown measures, particularly the temporary closures of productive facilities. An extended version of IRIO-LockI (Reissl et al., 2022a) additionally captures the relationship between changes in mobility (resulting from social distancing measures) and households' final consumption demand, decomposed into three broad categories corresponding to essential, intermediate and inessential needs. As for the other papers previously discussed, IRIO-LockI does not compute each firm's total desired production (implied by expected final demand) through the analytical solution provided by the Leontief quantity model. Instead, sectors' production decisions are made as follows. Sectors form short- and long-term expectations of—final plus intermediate—demand for their products. Short-term expectations equal demand received in the previous period, plus a factor accounting for the effect of possible lockdown measures. They determine sectors' current demand for labor and for intermediate inputs to be used in the next period, replacing those expected to be used up in current period production. Long-term expectations, instead, are an average of past demand over a certain amount of periods. They determine a target level of input inventories that sectors wish to hold to be able to maintain production at a level expected in the longer term; sectors will therefore demand additional intermediate inputs to adjust their inventories to the target level. Lastly, sectors know the current final demand for their products. As a result, each sector knows the exact level of actual demand for its products in the current period and therefore produces a certain amount, which may be less or equal to actual demand depending on whether its production factors (labor and intermediate inputs inherited from the previous period) are sufficiently available.

D'Alessandro et al. (2020) develop a SFC system dynamics model to investigate the long-term macroeconomic, environmental and distributional consequences of different environmental and social policies. One compelling takeaway of their analysis is that if climate change and inequality are to be mitigated at the same time, environmental policies are not enough and thus policymakers must couple them with radical social policies such as job guarantee and working time reduction programs. As for the methodological side, the model features ten industries that trade intermediate inputs in the form of energy products. Differently from the contributions that have previously been discussed, here the Leontief quantity model is actually used to compute each sectors' total required production as a result of final demand. However, since intermediate inputs comprise only energy products, the only sectors for which the computation is relevant—meaning that total required production is larger than final demand—are the energy sectors.

We believe that enriching a macroeconomic model with the Leontief quantity model, while technically demanding, offers some advantages. Imagine that we have a dynamic macro model with an input-output structure featuring n industrial sectors. Now assume that, in the current period, expected final demand for good j produced by industry

j increases by a certain amount, while expected final demand for the other products doesn't change. Sector j will need some intermediate inputs from the other sectors in order to produce its own product. However, those sectors will also require intermediate inputs in order to produce the goods demanded by sector j. Therefore, they'll demand those inputs to their suppliers, which will also need some intermediate inputs, and so on. As a result of increased production, some sectors may want to hire additional labor, invest to increase their capital stock, and may require external financing to do so. Using the Leontief quantity model in our framework allows us to capture all these round-by-round effects within one period, which in our model is assumed to represent a year. Instead, in the models mentioned above these round-by-round effects do not occur in one period but are spread over several periods, with one period accounting for only one round-by-round effect. Indeed, in those models' frameworks an increase in expected final demand for product j implies that sector j will increase its demand for intermediate inputs in the current period, but that demand will impact the suppliers' production only in the next period, while the latters' implied demand for intermediate inputs will impact the respective suppliers' production in the following period, and so on. Also the resulting increase in demand for labor, investment and external finance will be lagged according to the same story. This makes the interpretation of the overall effect of the initial change in expected final demand less clear, since in a dynamic macroeconomic model in each time step there are several changes occurring at the same time[5].

3 The model

Our macroeconomic SFC input-output model features an aggregate household, an aggregate bank, a government, a central bank, and six industries/sectors (we use the two terms as synonyms), namely:

- a minerals industry, which extracts and processes minerals;
- a fossil fuels industry, which extracts and processes fossil fuels;
- a green electricity industry, that employs green energy technologies to deliver electricity and benefits from grid priority;
- a brown electricity industry, that converts fossil fuels inputs into electricity through brown energy technologies, and fulfills the electricity demand that could not be covered by the green producer;
- a manufacturing industry, which produces manufactured products;
- a miscellaneous industry, comprising all other industries not listed above, such as services and agriculture.

For the sake of clarity, there are five goods in our economy, since purchasers do not distinguish between green and brown electricity. In summary, we have six industries/sectors producing five goods.

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[5] This lagged round-by-round mechanism is however a reasonable one for a model such as that of Reissl et al. (2022b), where a period represents a week and the model aims at reproducing the dynamic effects of lockdown measures that occurred in reality.

Each of the six sectors requires all five goods as intermediate inputs to produce its specific good, according to fixed technical coefficients derived from input-output tables. The only other production factor of our sectors is fixed capital, which may constrain production if not available in sufficient amount. For simplicity, we assume labor away: our aggregated household is a capitalist that owns all companies and the bank and accordingly receives dividend payments.

In this first version of our model, we assume that each of the six sectors above is populated just by one representative company. Therefore, while the model features heterogeneous interacting agents/industries, for the time being we do not model heterogeneous agents within each industry. Indeed, to address the research questions raised in the Introduction, we believe that it is useful to start with a relatively simple model that is already well-suited for the task. Allowing for heterogeneity within each sector may be especially useful if one wants to study the innovation dynamics occurring in each industry, or the propagation of climate-related financial risks in the network of customers, suppliers, and investors. We may address such issues in a future version of the model.

There is only one real asset in our economy, namely real capital of industries. Instead, there are four financial assets/liabilities: bank deposits, bank loans, central bank reserves, and central bank advances. Figure 8 and Figure 9 in Appendix A show, respectively, the balance sheet matrix and the transactions flow matrix of our model[6].

3.1 Calibration of crucial parameters

We use input-output tables downloaded from the Exiobase 3 database[7] to set the following parameters of our model:

(i) technical coefficients, that describe intermediate inputs requirements for each industry, as detailed in Section 3.4;

(ii) the goods composition of the generic capital good, which will also be described in more detail in Section 3.4;

(iii) the household's desired consumption proportions of the five goods, as discussed in Section 3.5.

All these parameters express physical (i.e. real, not nominal) quantities. For example, a technical coefficient in our model captures the units of a certain product needed as intermediate inputs to produce one unit of another product.

Exiobase provides environmentally extended input-output tables featuring 44 countries, 5 rest of the world regions, and 163 industries[8]. We first aggregate data referring to each of the 163 industries across different countries and regions to obtain world-level data for each industry. Then, we aggregate the 163 industries' data to obtain values referring to the six industries of our model. For example, to obtain data related to our fossil fuels industry, we have aggregated the following industries featured in Exiobase:

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[6] These matrices are typical of Stock-Flow Consistent models.

[7] The Exiobase 3 database can be accessed at the following link: https://doi.org/10.5281/zenodo.5589597

[8] Specifically, we use the monetary version of the Exiobase 3 dataset, but there is also a version expressed in hybrid units.

- Mining of coal and lignite; extraction of peat;
- Extraction of crude petroleum and services related to crude oil extraction, excluding surveying;
- Extraction of natural gas and services related to natural gas extraction, excluding surveying;
- Extraction, liquefaction, and regasification of other petroleum and gaseous materials;
- Manufacture of coke oven products;
- Petroleum Refinery;
- Manufacture of gas; distribution of gaseous fuels through mains.

So, the fossil fuels industry in our model comprises activities related to both extraction and processing of fossil fuels, including coal, oil, and gas.

While data in the Exiobase 3 version that we use are expressed in monetary terms, as mentioned above we claim that the parameters we derive from Exiobase express physical quantities. This can be reasonably pretended by assuming initial prices in the model to be equal across all goods (e.g. unitary prices for all goods), and by letting the physical unit of each good be defined as the one that can be exchanged at that price.

3.2 Sequence of events

In each time step of our simulations—where each time step represents a year—the following sequence of events occurs (details are discussed in the following subsections):

1. Industries form expectations of the final demand for their products that they will face in the current period.
2. Given these expected final demands, the Leontief quantity model computes the implied total production required from each industry. The tricky part here is to account for: (i) substitutability of green and brown electricity, with grid priority for the former; (ii) production constraints arising from capital availability; (iii) production constraints arising from shortages in intermediate inputs. Our innovative algorithm accounts and solves for all these issues, delivering the current green share in electricity production, sectors' actual production, and products available for sale to final demand.
3. Sectors set their prices as a variable mark-up on their unit costs.
4. Households formulate their nominal demand, which depends on dividend income received in the former period and their previously accumulated wealth.
5. Sectors sell their final products to final demand actors, according to the following pecking order: first, investing sectors are served; what is left over is sold to the household if demanded. If available products are less than final demand, some final demand actors will be rationed. For simplicity, we do not allow for inventories, so that unsold products are perishable and do not last until the next period.

6. Industries determine the amount of investments they wish to make in the next period. Then, they compute the Net Present Value (NPV) to decide whether to actually engage in the investment process or not. If the NPV is positive, they go to the bank and ask for a loan to cover the investment costs that they expect to incur in the next period.

7. The bank creates all the loans it can, subject to regulatory capital requirements. If the bank is not able to supply the entire amount of loans requested, it cuts loans to all its customers according to the same credit constraint. For simplicity, we assume that the interest rate applied by the bank on its loans is constant over time[9].

8. If sectors are credit rationed, they revise their investment plans accordingly. The resulting investment plans are transformed into orders that are sent to suppliers, such that when in the next time step the suppliers will form their expectations of final demand, they take into account the orders that have been placed by investing sectors.

9. Sectors pay taxes to the government. The green electricity sector may receive subsidies from the government for its new investments.

10. If not in distress, the bank and the industries distribute dividends to the household.

11. Sectors may pay back some of their outstanding loans.

12. The bank may ask for central bank loans if needed.

13. If the government doesn't have enough funds to cover its deficit, it demands loans from the central bank. If the debt-to-GDP ratio is below a floor value, the government decreases the tax rate. If the debt-to-GDP ratio is above the a ceiling value, the government increases the tax rate.

14. The central bank accomodates the loans requested by the government and by the bank.

3.3 Notation

We use the following notation:

- N_{goods} is the number of goods, which is equal to five—recall that we have the following products: minerals, fossil fuels, manufacturing, miscellaneous, and electricity. N_{ind} is the number of industries, which is equal to six—recall that we have the following sectors: minerals, fossil fuels, manufacturing, miscellaneous, green electricity, and brown electricity.

- Bold lowercase letters represent vectors. For example, $\mathbf{d}_{goods,\ t}$ is a vector of length N_{goods} that represents period's t real final demand for each good.

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[9] While this is a considerable simplification—which will be relaxed in future extensions of our model—it allows us to keep the first version of our model as simple as possible, thereby facilitating interpretation of results, which are meant to highlight the structural features of the model.

- Bold uppercase letters represent matrices. For instance, $\mathbf{S}_t$ is the N_{ind}xN_{ind} matrix of real intermediate inputs transactions that occur between the N_{ind} sectors in period t.
- The tilde symbol represents expectations. So, $\tilde{\mathbf{d}}_{goods,\ t}$—of length N_{goods}—is expected final demand of the N_{goods} goods at time t.
- The hat symbol stays for agents' desires or plans. For illustration, $\hat{\mathbf{q}}_t$—of length N_{ind}—represents desired production by sectors.

3.4 Industries

3.4.1 Production factors

To produce, each of our six sectors relies on two complementary production factors: capital and intermediate inputs. For each industry, if either capital or intermediate inputs are not available in sufficient amount, production will be constrained. In the remaining part of this section we will discuss the two production factors in detail.

We assume that there are two types of capital goods in the economy: a green-energy capital good—used by the green electricity sector—and a generic capital good—used by all other sectors. Each of the two capital goods is made up of fixed physical proportions of the five goods characterizing our economy, as shown in Table 1. The proportions describing the generic capital good are derived from Exiobase input-output tables, which comprise a vector of aggregate investment in an economy, showing how this aggregate investment expenditure is spread across the different goods and services in the period under consideration. In other words, input-output tables do not report sector-specific investment proportions, e.g. they do not show how the mining or the fossil fuels sectors have invested by purchasing different goods and services. Instead, they account for aggregate investment behavior. This is the reason why we have to assume a generic capital good, and cannot have specific capital goods for each sector. The only exception is the green-electricity sector, because it is our aim to investigate the implications of an increase in green energy investments. Following the considerations made in the Introduction, we simply assume that the green capital good has a much higher proportion of minerals, and a much smaller proportion of manufacturing goods, compared to the generic capital good. Instead, we believe it is reasonable to assume that the share of the generic good (which mainly comprises services) is basically the same in the two capital goods. For simplicity, we set the proportions of fossil fuels and electricity to zero for the green capital good.

In our model, when a sector wants to increase its capital stock by investing a certain amount, it has to purchase the goods comprising its capital good according to those (fixed) proportions—and those goods are not substitutable between each other[10]. If sector j—suppose this is the green sector—wants to increase its capital stock by $\Delta\hat{k}_{j,t}$ new units of green capital goods, this will imply that it needs to purchase $45n\Delta\hat{k}_{j,t}$ units of minerals, $40n\Delta\hat{k}_{j,t}$ units of manufacturing goods, and $15n\Delta\hat{k}_{j,t}$ units of miscellaneous goods, where n is a scaling factor that converts units of capital to units of component goods. It is

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[10] Perfect complementarity implies that if all but one goods necessary for investment by sector j are available in sufficient amount, with the one good available only at 50% of the necessary amount, then sector j will be forced to invest only 50% of the amount originally planned for, and will thus buy 50% of the planned amount of all goods.

Table 1: Compositions of generic capital good (derived from Exiobase input-output tables) and green capital good (assumed).

Goods	**Generic capital good** (Exiobase)	**Green capital good** (assumed)
Minerals	1.8%	45%
Fossil fuels	1.3%	0%
Manufacturing	82.0%	40%
Miscellaneous	14.9%	15%
Electricity	0.1%	0%

Table 2: Technical coefficients in physical terms, derived from Exiobase input-output tables.

	Industries					
Goods	Minerals	Fossil fuels	Manufacturing	Miscellaneous	Green electricity	Brown electricity
Minerals	0.372	0.016	0.066	0.004	0.009	0.010
Fossil fuels	0.035	0.343	0.023	0.014	0.070	0.288
Manufacturing	0.098	0.053	0.373	0.071	0.067	0.108
Miscellaneous	0.156	0.127	0.176	0.280	0.160	0.190
Electricity	0.024	0.016	0.010	0.008	0.012	0.012

assumed that the sector is then able to assemble those goods into its capital good at no additional cost.

We assume that sectors also need fixed physical proportions of intermediate inputs to produce their industry-specific product. By dividing the s_{ij} units of intermediate inputs of good i needed by sector j to produce q_j units of its product, one obtains a technical coefficient in physical terms, $c_{ij} = s_{ij}/q_j$, representing the units of intermediate inputs of good i needed to produce one unit of sector's j product. These technical coefficients are derived from Exiobase input-output tables, and are shown in Table 2. For example, the green electricity column shows that to produce one unit of electricity the green sector needs—as intermediate inputs—0.07 units of fossil fuels, 0.067 units of the manufacturing good, 0.16 units of the miscellaneous good, and so on. By contrast, as may be expected, to produce one unit of electricity the brown sector needs much more intermediate inputs than the green sector, especially in the form of fossil fuels (0.288 units). The reader may notice that technical coefficients describing a sector's requirements for its own product tend to be higher than the other technical coefficients of that sector. The reason is that technical coefficients for each of our industries have been obtained by aggregating data over different industries featured in Exiobase, as explained in Section 3.1. So, for example, our fossil fuels industry has a high technical coefficient versus itself because it represents activities related to both extraction and processing of fossil fuels. Obviously, activities related to the processing of fossil fuels purchase a huge amount of intermediate inputs (fossil fuels) from activities related to the extraction of fossil fuels.

3.4.2 Production

At the beginning of each period, industries form expectations of the real final demand for their products that will occur in the current period. While final demand from the

Table 3: Example of square technical coefficients matrix, implied by a green share of 50%.

	Industries					
Industries	Minerals	Fossil fuels	Manufacturing	Miscellaneous	Green electricity	Brown electricity
Minerals	0.372	0.016	0.066	0.004	0.009	0.010
Fossil fuels	0.035	0.343	0.023	0.014	0.070	0.288
Manufacturing	0.098	0.053	0.373	0.071	0.067	0.108
Miscellaneous	0.156	0.127	0.176	0.280	0.160	0.190
Green electricity	0.012	0.008	0.005	0.004	0.006	0.006
Brown electricity	0.012	0.008	0.005	0.004	0.006	0.006

household is unknown, final demand from investing industries ($\mathbf{d}^{inv}_{goods,\ t-1}$) and from the government ($\mathbf{d}^{gov}_{goods,\ t-1}$) is known since it has already been ordered in the previous period. So, expected final demand $\tilde{\mathbf{d}}_{goods,\ t}$ is a vector of length N_{goods} defined as

$$\tilde{\mathbf{d}}_{goods,\ t} = \tilde{\mathbf{d}}^{cons}_{goods,\ t} + \mathbf{d}^{inv}_{goods,\ t-1} + \mathbf{d}^{gov}_{goods,\ t-1}$$

where $\tilde{\mathbf{d}}^{cons}_{goods,\ t}$ is expected final demand from the household and is defined as $\tilde{\mathbf{d}}^{cons}_{goods,\ t} = \mathbf{d}^{cons}_{goods,\ t-1}$ (naive expectations).

Given expected real final demand, using the Leontief quantity model $\mathbf{q} = \big(\mathbf{I} - \mathbf{C}\big)^{-1}\tilde{\mathbf{d}}_t$—where $\mathbf{I}$ is a square identity matrix and $\mathbf{C}$ is a square technical coefficients matrix—would yield the vector of total real production by each industry, $\mathbf{q}$. However, we cannot apply this formula right away since we have to deal with the following complications:

(i) we don't have a square technical coefficient matrix but a rectangular one, as shown in Table 2;

(ii) we want to have perfect substitutability for electricity produced by the green and the brown industries, with grid priority for the green sector;

(iii) production constraints may arise if the capital stock of one or more sectors is insufficient to meet the requested production level.

Our innovative computational algorithm is able to account for all these complexities. The first two complications are tackled by finding the maximum share in electricity production that can be covered by the green sector[11]. For example, if our algorithm finds that this share is 50% in the current period, the resulting technical coefficients square matrix $\mathbf{C}_t$ in the current year is as reported in Table 3. As can be seen, the rows related to non-electricity goods/industries are the same as those in Table 2. Instead, the electricity row in Table 2 has been split into green and brown electricity rows in Table 3, with coefficient values derived according to a 50% proportion. Finally, expected final demand for electricity will also be spread across the green and brown sectors according to a 50% proportion.

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[11] It is not a straightforward task to find the maximum green share. Indeed, whenever the green proportion in electricity production is fine tuned, the entire total production vector changes, including total production requirements of both non-electricity and electricity goods. This is because the green and the brown electricity sectors have different technical coefficients, as can be seen from the respective columns in Table 2.

The third complication is accounted for by relying on the Mixed input-output model methodology (Miller and Blair, 2009, Ch. 13), which is an adaptation of the Leontief quantity model to the case where production in one or more industries is constrained. The idea is that for a constrained sector, instead of having final demand as the independent variable and total production as the dependent variable, the maximum production level is set as the independent variable while the amount of products available for sale to final demand is the dependent variable. The idea is that a constrained sector will produce at its maximum level, it will then prioritize sales to intermediate demand from industries, and what is left over will be made available for sale to final demand.

The problem with this approach is that the amount of products available for sale to final demand could even become negative. We therefore amend the Mixed input-output model methodology by setting a floor of zero to the amount of products available for sale to final demand of the constrained sector. If a constrained sector hits this floor, we compute the associated production constraint[12] and use this constraint as a haircut of the expected final demands for the other goods to find an adjusted final demand vector, which is then used to compute total production through the standard Leontief quantity model. For example, if the production constraint turns out to be 80%, the adjusted final demand vector will comprise a value of zero for the constrained sector, while it will comprise values equal to 80% of the expected final demand levels for all other sectors. The idea behind this approach is that the constrained sector, while sacrificing its final demand, supplies 80% of the demanded amounts to all its intermediate inputs customers. Therefore, the latter will be able to produce only 80% of their originally planned level, because of the shortage of the intermediate input provided by the constrained sector. As a result, these downstream sectors will be able to satisfy only 80% of their expected final demand. Therefore, this is equivalent to using the Leontief quantity model with a final demand rescaled at 80% of the original level. It should be noted that a production constraint arising initially in just one sector will propagate to all other industries because all industries are connected with each other by exchanging intermediate inputs.

To summarize, in any period in our model the initial constraint on an industry's production—if present—is always a result of an insufficient level of capital. However, as a result of this original production constraint, further production constraints may arise in downstream industries if intermediate inputs from the constrained sector are not sufficiently available for its customers. If this is the case, production constraints will propagate to all industries, since these are fully connected to each other.

In the following, we express in mathematical form the mechanisms depicted above, namely how from an expected final demand we compute actual production and products available for sale to final demand. Let $\mathbf{DEP}_t$ be a vector of length N_{ind} of dependent variables; let $\mathbf{INDEP}_t$ be a vector of length N_{ind} of independent variables; let $\tilde{\mathbf{d}}_t$ be a vector of length N_{ind} featuring final demand expected by each industry; finally, let $\mathbf{q}_t^s$ be a vector of length N_{ind} representing total production by each industry (s stands for supply). Then,

---

[12] This production constraint is defined as the ratio between maximum production and required production, where the latter is obtained from the Leontief quantity model with final demand for the constrained sector's good set to zero, while the other final demands are the originally expected ones.

$$
\mathbf{DEP}_t = \begin{cases} \big(\mathbf{I} - \mathbf{C}_t\big)^{-1} \cdot \mathbf{INDEP}_t, & \text{if there are no constraints. This is the Leontief quantity model formula. In this case, } \mathbf{INDEP}_t = \tilde{\mathbf{d}}_t \text{ and } \mathbf{DEP}_t = \mathbf{q}_t^s. \\ \mathbf{M}_t^{-1}\mathbf{N}_t \cdot \mathbf{INDEP}_t, & \text{if there are capital constraints, but no intermediate inputs constraints. This is the Mixed model formula; for the definition of the matrices } \mathbf{M} \text{ and } \mathbf{N}\text{, see Miller and Blair (2009, Ch. 13.2). In this case, } \mathbf{INDEP}_t \text{ contains expected final demand for unconstrained sectors and maximum production for the constrained sector, while } \mathbf{DEP}_t \text{ contains total production of unconstrained sectors, and—for the constrained sector—available products for final demand sales.} \\ \big(\mathbf{I} - \mathbf{C}_t\big)^{-1} \cdot \mathbf{INDEP}_t^{adj}, & \text{if there are capital constraints and intermediate inputs constraints. This is the Leontief quantity model formula. In this case, } \mathbf{INDEP}_t^{adj} = \tilde{\mathbf{d}}_t^{adj}\text{, where } \tilde{\mathbf{d}}_t^{adj} \text{ is zero for the initially constrained sector, and is equal to final demand adjusted through the haircut for all other sectors. Finally, } \mathbf{DEP}_t = \mathbf{q}_t^s. \end{cases}
$$

3.4.3 Investment

Industries start considering whether to invest whenever their maximum production level—determined solely by their capital stock and their capital productivity—is lower than their desired production level. We define the desired production level of the green sector to be the production level implied by a 100% green share in electricity production, which of course is always greater than the maximum production level of the green sector unless the economy has already fully decarbonized. We define the desired production level of all other sectors to be the one resulting from the Leontief quantity model with the green share being consistent with the maximum production reachable by the green sector.

If in the current year a sector's maximum production level is lower than its desired production level, then the sector may want to increase—next year—its capital stock by some amount to be able to potentially cover part of that production gap in the future. The decision of whether to invest or not is made by computing the Net Present Value of investment. Suppose that sector j is considering to increase its capital stock by $\Delta\hat{k}_{j,t}$ new units of capital goods. To this purpose, industry j computes the NPV of increasing its capital stock by $\Delta\hat{k}_{j,t}$ units for a total planned investment cost $\widehat{IC}_{j,t}$ subsidized for $100\xi\%$ by the government (this is a green subsidy and may be larger than zero only for the green electricity sector). Industry j expects to be able to sell the goods produced through the new capital at the latest market price $p_{j,t}$, assumed to stay constant in all future time steps. The NPV is then given by:

$$
NPV_{j,t} = -(1-\xi)\widehat{IC}_{j,t} + \frac{p_{j,t} \cdot \varepsilon_j \Delta\hat{k}_{j,t}}{r_l + \delta_j}
$$

where δ_j is depreciation of sector j's capital, ε_j is productivity of sector j's capital, and r_l shall be considered as the cost opportunity of capital used to discount future cash flows and is proxied by the cost of debt (i.e. the interest rate applied by the bank on loans).

If its NPV is negative, sector j will abandon its investment plans. If the NPV is positive, sector j proceeds with the desired investment process by asking the bank for a loan, which the sector needs in order to cover the full investment cost that it expects to incur in the next period. The bank will provide the loan as requested unless its regulatory capital requirement is binding, in which case the bank will provide only a portion of the requested loan to comply with capital regulation. If sector j receives only a share of the desired loan, it will accordingly revise its investment plans downwards. Finally, sector j will order the amounts of goods implied by its desired investment—computed as entailed from the proportions shown in Table 1—at the respective suppliers, to be delivered in the next period.

However, it is not granted that the goods necessary for sector j's investment will actually be fully delivered in the next year. Indeed, production constraints may arise in the next period, implying that one or more goods may not be available in sufficient amount. Suppose that sector j is the minerals sector. Its capital good is of the generic type—as explained in Section 3.4.1—meaning that all five goods in the economy are needed to build up its capital stock. Now, suppose that all goods are available in sufficient amount, except for the manufacturing good, which is available only at e.g. 70% of the ordered amount. Then, since goods are not substitutable, sector j will purchase 70% of the ordered amounts of all goods, and will invest 70% of the planned level.

3.4.4 Price setting

Each j^{th} sector sets its price $p_{j,t}$ by applying a variable markup $\mu_{j,t}$ on its unit costs $uc_{j,t}$:

$$p_{j,t} = (1 + \mu_{j,t}) \cdot uc_{j,t}$$

Unit costs equal intermediate inputs costs per unit plus depreciation of capital per unit of produced goods. The variable markup moves within a range, depending on the discrepancy of supply versus expected demand. The more the supply is abundant compared to expected demand, the lower the markup.

$$\mu_{j,t} = \begin{cases} \mu^{max} & \text{if } \tilde{d}_{j,t} > (1 + \mu^{max}) \cdot q^{s,final}_{j,t} \\ \mu^{min} & \text{if } \tilde{d}_{j,t} < (1 + \mu^{min}) \cdot q^{s,final}_{j,t} \\ \frac{\tilde{q}^{d}_{j,t}}{q^{s,final}_{j,t}} - 1 & \text{otherwise.} \end{cases}$$

However, since the price of electricity has to be the same, we set it to be the highest resulting price among the green and brown sector, which is in accordance with how pricing currently occurs in European electricity markets—given by the marginal price at the intersection of demand and supply curves.

3.5 The aggregate household

Our aggregate, representative household is a capitalist that owns the bank and all the industries and accordingly receives dividend payments $DIV_{h,t}$, which the banks and the industries disburse whenever they are not in distress. What is left over of this property income after consumption is accumulated as bank deposits, which is the household's stock of wealth or net worth $NW_{h,t}$ (the household has no liabilities). The household

Table 4: Household's desired consumption proportions (derived from Exiobase input-output tables).

Goods	**Consumption proportions**
Minerals	0.67%
Fossil fuels	3.11%
Manufacturing	28.05%
Miscellaneous	67.00%
Electricity	1.18%

desires to consume a total nominal amount—which we define as its consumption budget $CB_{h,t}$—given by the following equation:

$$CB_{h,t} = \alpha_1 DIV_{h,t} + \alpha_2 NW_{h,t}$$

where α_1 is the propensity to consume out of income and α_2 is the propensity to consume out of wealth. The household spreads this total nominal consumption budget across the five different goods according to fixed proportions derived from Exiobase's input-output tables (reported in Table 4), and demands the resulting units of goods from industries. In any year, household's demand for any good may not be fully satisfied if the amount of goods available for sale to final demand is lower than final demand itself.

3.6 The aggregate bank

Our representative bank collects deposits from the household and from sectors, and provides loans to industries following the endogenous money approach (Deleidi and Fontana, 2019). Credit creation may be constrained, though, by regulatory capital requirements.

3.7 Government and central bank

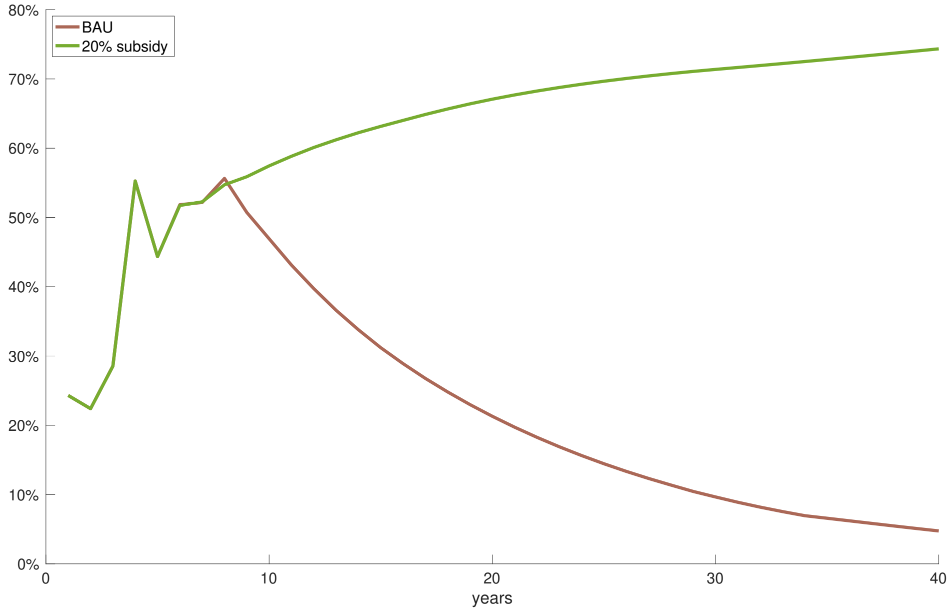
The government levies a variable tax rate on industries' profits. If the debt-to-GDP ratio is below a floor value, the government decreases the tax rate. If the debt-to-GDP ratio is above the a ceiling value, the government increases the tax rate. Government's outflows take the form of subsidies for green electricity investments. If the government doesn't have enough funds to cover its deficit, it demands loans from the central bank. The central bank accomodates the loans requested by the government.

4 Simulations

We run the model over a time span of 40 years for two different scenarios:

1. a business as usual (BAU) scenario, with no green policy;
2. a green policy scenario with a 20% subsidy for the green sector, meaning that the latter receives a subsidy for its investments in the form of a 20% refund for its investment costs from the government. In what follows, this scenario will be simply referred to as the "green scenario".

Figure 2: Green share in electricity production.



It should be noted that the results presented in the following should not be interpreted as definitive—the model is not in its final version yet and some parameters are still to be fine tuned—but rather as results that shed light on the structural features of our model and already provide some interesting insights.

In the following figures, brown lines/bars are related to the BAU scenario, while green lines/bars are related to the green scenario. As shown in Figure 2, in the BAU simulation the green share in electricity production increases during the first ten years, while it declines during the remaining years of the simulation as a result of a halt in investments by the green electricity industry. The green sector stops investing because the NPV becomes negative, which is the result of too high investment costs. By contrast, in the green scenario—thanks to the subsidy—the NPV of green investments is always positive, the green industry thus steadily invests and the green share reaches a level of around 75% at the end of the simulation.

Figure 3 shows the dynamics of real GDP (left panel) and real aggregate investment (right panel) in our economy. Interestingly, real GDP and real investment reach a higher level in the BAU compared to the green scenario. It turns out that the reason of this result is that an economy whose electricity system has not been decarbonized requires the production of much more intermediate inputs than an economy that has greened its electricity system[13]. A higher requirement of intermediate inputs entails that industries will have to produce more, and will thus also invest more as they need a higher level of capital stock to meet increased production levels. This mechanism can be seen in more detail by looking at the final demand sales, intermediate inputs sales and total production by each of our six industries—as shown in Figure 4, Figure 5, and Figure 6, respectively[14].

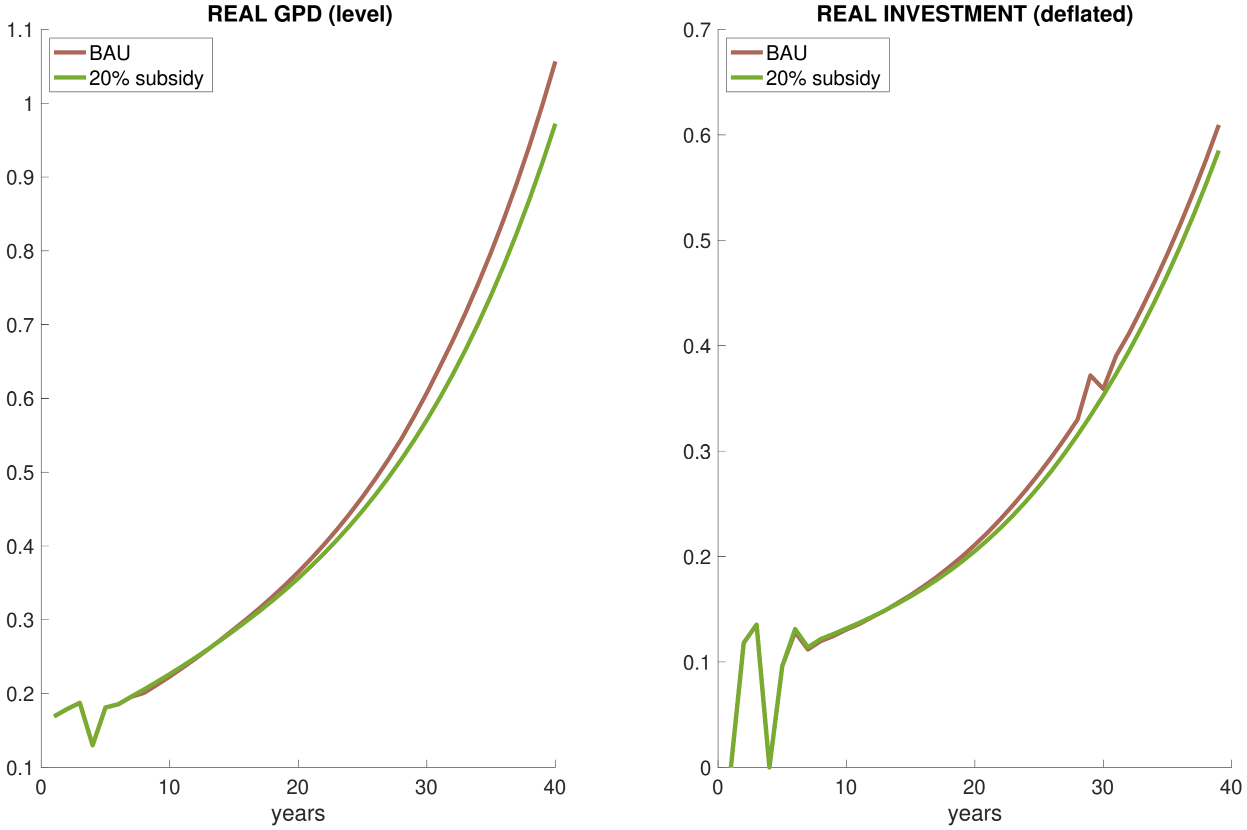
The final demand sales (including sales to investing companies and to the household) bar plot shows that—compared to the BAU scenario—in the green scenario:

---

[13] This can be seen from the green and brown electricity industries' technical coefficients reported in the respective columns of Table 2.

[14] These bar plots report average values over the second half of the simulation period—i.e. the last 20 years—to avoid accounting for the initial adjustment period.

Figure 3: Real GDP and real investment



- obviously, final demand sales by the green sector sharply increase (+645%), while the opposite happens for the brown sector (-67%);

- final demand sales by the minerals industry more than doubles (+124%): the reason is that green investments require a huge amount of minerals, as discussed in the Introduction and as reported in Table 1;

- final demand sales by the manufacturing and miscellaneous industries decline both by 9%;

- final demand sales by the fossil fuels sector almost remains constant (+1%).

Regarding intermediate inputs sales, the bar plot in Figure 5 shows that while sales of minerals and of electricity almost remain constant across the two scenarios, with the transition to a green economy intermediate inputs sales by the other sectors decrease by significant amounts.

The combined effect of final demand sales and intermediate inputs sales is made explicit in the bar plot reporting total production (Figure 6). As was to be expected, transitioning to an economy based on renewables implies an increase in the relative weight of the green electricity and minerals industries, while a decline in the relative weight of all other industries. The sectors that suffer most from the energy transition are—as expected—the brown electricity sector (-70%) and the fossil fuels industry (-10%).

Finally, it is informative to look at the dynamics of each industry's stock of capital across the two scenarios—as reported in Figure 7. Consistently with the above story, the

Figure 4: Real final demand sales (average, units)

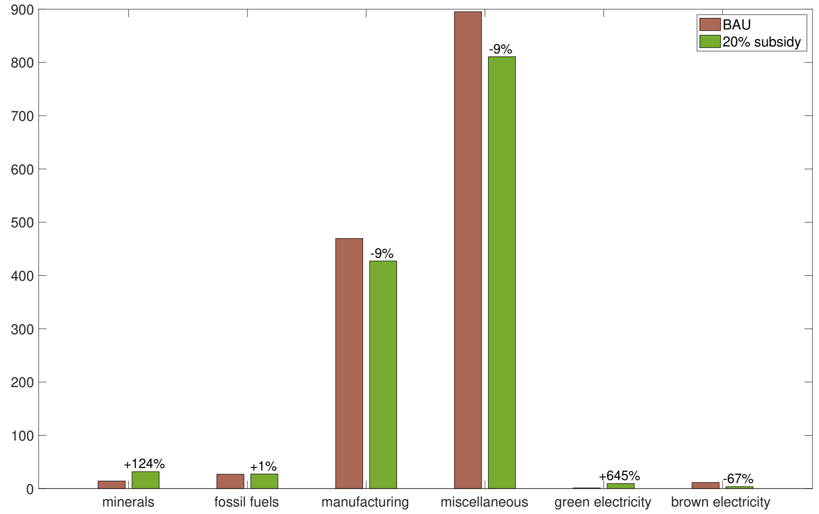


Figure 5: Real intermediate inputs sales (average, units)

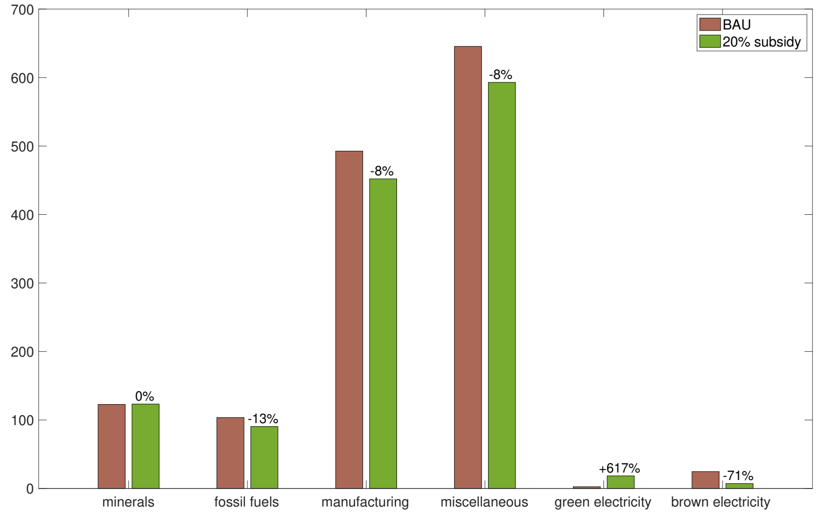


Figure 6: Real production (average, units)

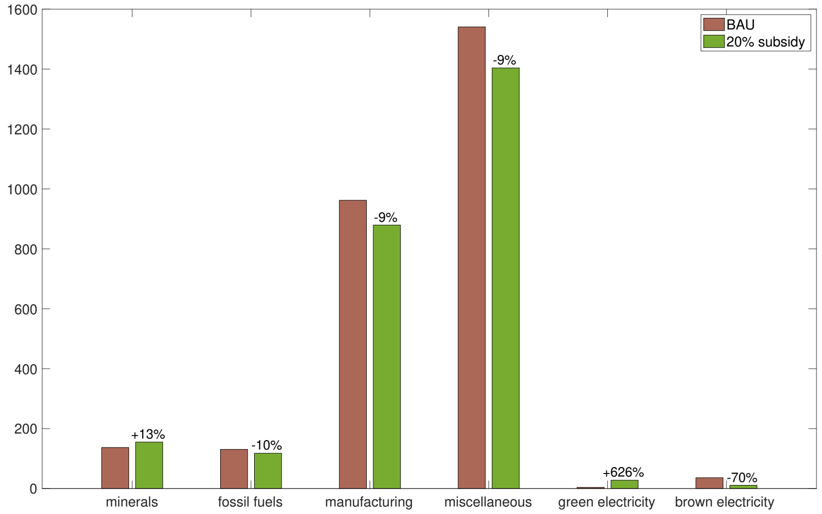
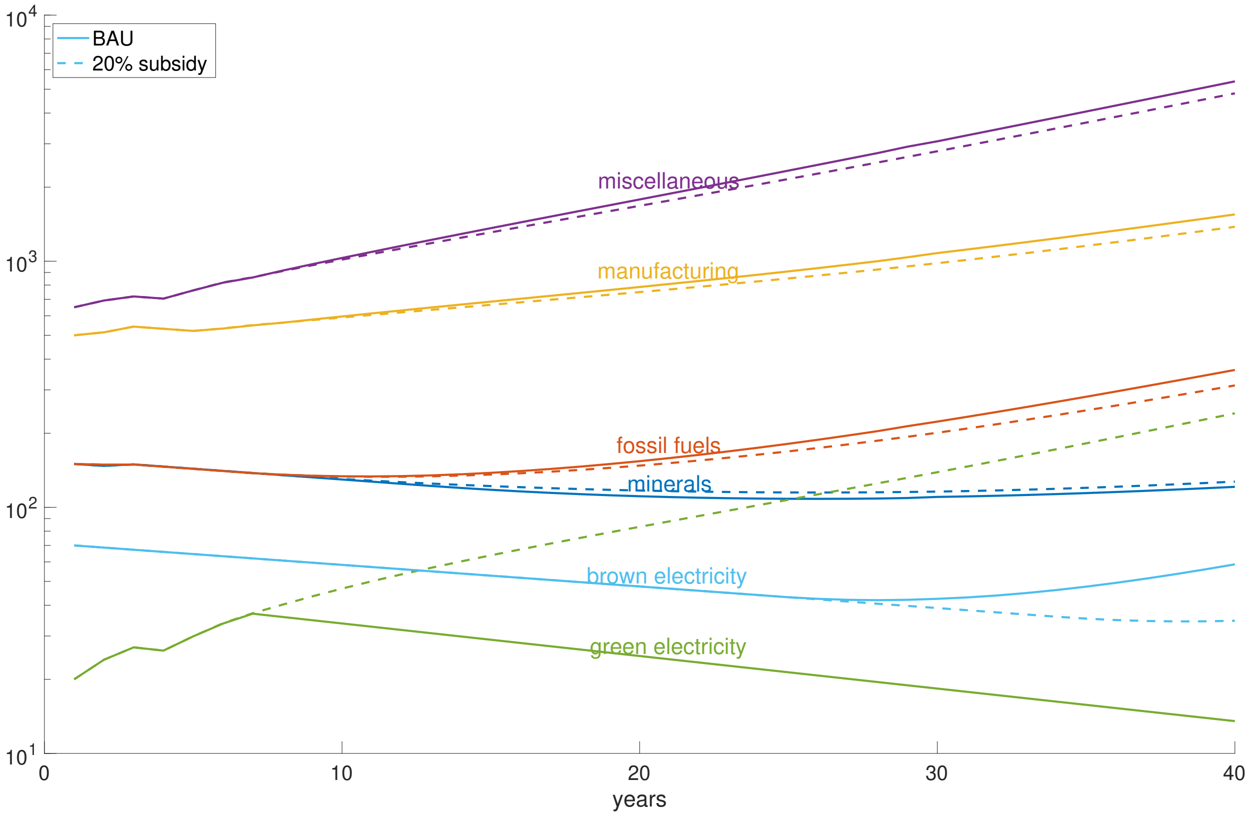


Figure 7: Real capital (units, log scale)



only sectors that invest more in the green policy scenario compared to the BAU scenario are the green electricity and the minerals industries. All other industries experience a decrease in their capital stock.

To conclude, our model shows that the role of intermediate inputs is non-neutral and that they actually play a pivotal role in shaping both macroeconomic and mesoeconomic dynamics. A low-carbon economy is characterized by a lower level of intermediate inputs requirements, compared to a high-carbon economy. This is quite intuitive: fossil fuels are replaced by free, renewable resources such as sun and wind. Green electricity production requires a lower amount also of all other intermediate inputs—such as manufacturing and services—compared to brown electricity production (see Table 2). This decline in intermediate consumption from electricity producers has the direct implication of decreasing the production of the related suppliers, which will therefore demand a lower amount of intermediate inputs as well, thereby impacting their own suppliers, and so on, with the initial effect cascading through all the network of suppliers. As a result, many sectors will invest less since they are required to meet a lower production level than before.

While these results highlight the structural importance of modeling intermediate inputs into a macroeconomic framework, they should not be taken as realistic and definitive conclusions. For example, our model does not account (yet) for the impact of climate change on the economy, by abstracting from climate damages. Once accounted for, damages may negatively affect GDP in the BAU scenario, thereby potentially leading to a lower GDP level in the BAU compared to the green policy scenario.

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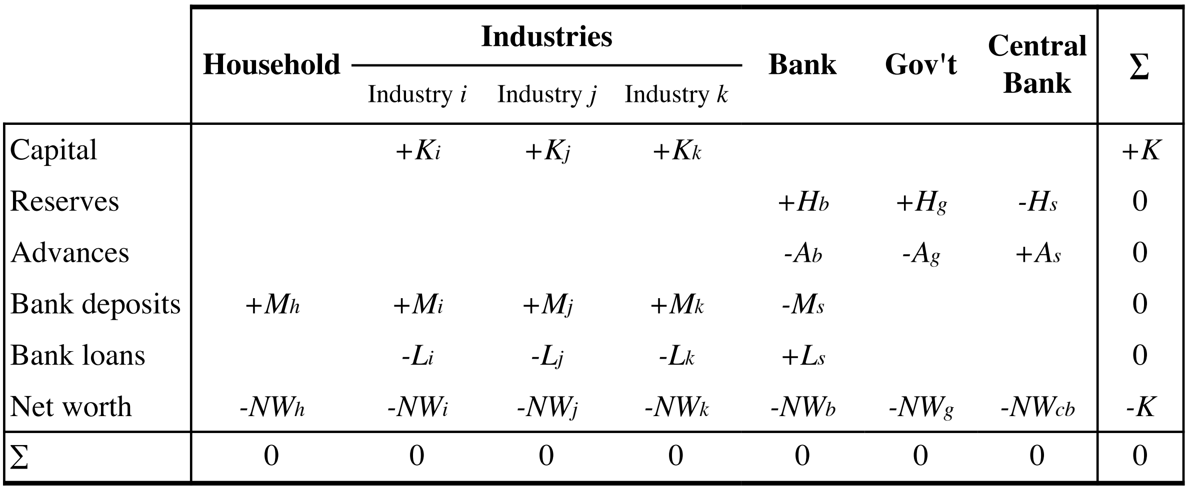
A Stock-Flow Consistent matrices

Figure 8: Balance Sheet matrix of our model.



	Household	**Industries**			**Bank**	**Gov't**	**Central Bank**	**Σ**
		Industry *i*	Industry *j*	Industry *k*				
Capital		$+K_i$	$+K_j$	$+K_k$				$+K$
Reserves					$+H_b$	$+H_g$	$-H_s$	0
Advances					$-A_b$	$-A_g$	$+A_s$	0
Bank deposits	$+M_h$	$+M_i$	$+M_j$	$+M_k$	$-M_s$			0
Bank loans		$-L_i$	$-L_j$	$-L_k$	$+L_s$			0
Net worth	$-NW_h$	$-NW_i$	$-NW_j$	$-NW_k$	$-NW_b$	$-NW_g$	$-NW_{cb}$	$-K$
Σ	0	0	0	0	0	0	0	0

Figure 9: Transactions Flow matrix of our model.

		Household	**Industry *i***		**Industry *j***		**Industry *k***		**Bank**		**Gov't**	**Central bank**	**Σ**
			Current	Capital	Current	Capital	Current	Capital	Current	Capital			
Consumption		$-C$	$+C_i$		$+C_j$		$+C_k$						0
Gov't consumption			$+G_i$		$+G_j$		$+G_k$				$-G$		0
Net Input use			$-IC_i$		$-IC_j$		$-IC_k$						0
Investment			$+I_{si}$	$-I_{pi}$	$+I_{sj}$	$-I_{pj}$	$+I_{sk}$	$-I_{pk}$					0
Taxes			$-T_i$		$-T_j$		$-T_k$				$+T$		0
Green subsidy				$+GS$		$+GS$		$+GS$			$-GS$		0
Firm profits		$+FD_f$	$-F_{fi}$	$+FU_{fi}$	$-F_{fj}$	$+FU_{fj}$	$-F_{fk}$	$+FU_{fk}$					0
Bank profits		$+FD_b$							$-F_b$	$+FU_b$			0
Interest on Loans			$-r_{l-1} \cdot L_{fi-1}$		$-r_{l-1} \cdot L_{fj-1}$		$-r_{l-1} \cdot L_{fk-1}$		$+r_{l-1} \cdot L_{s-1}$				0
Change in the stocks of..	advances									$+\Delta A_b$	$+\Delta A_g$	$-\Delta A_s$	0
	loans			$+\Delta L_{fi}$		$+\Delta L_{fj}$		$+\Delta L_{fk}$		$-\Delta L_s$			0
	reserves									$-\Delta H_b$	$-\Delta H_g$	$+\Delta H_s$	0
	deposits	$-\Delta M_h$		$-\Delta M_{fi}$		$-\Delta M_{fj}$		$-\Delta M_{fk}$		$+\Delta M_s$			0
Σ		0	0	0	0	0	0	0	0	0	0	0	0